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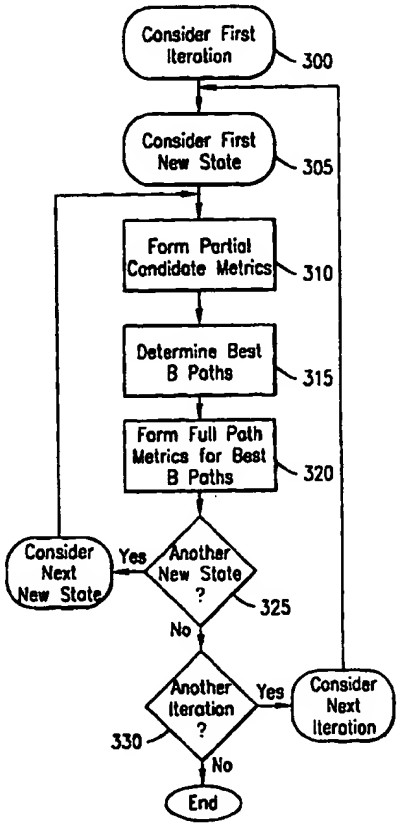
(54) Title: COMPUTATIONALLY EFFICIENT SEQUENCE ESTIMATION

(57) Abstract

An improved system and method for reducing the computational complexity of metric updating, such as within a maximum likelihood–sequence–estimation (MLSE) detector, used in, for example, demodulating a received signal subject to intersymbol interference. Complexity is reduced by eliminating the computation of common portions of a series of path metrics and perform a full computation of the next state after the optimum path to the next state has been determined. Alternatively, a primary path metric is determined and key components of secondary path metrics are examined to determine secondary path viability. If the secondary path is viable, the full secondary path metric is formed and compared to the primary path metric, which is replaced if the secondary is better.



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COMPUTATIONALLY EFFICIENT SEQUENCE ESTIMATION

BACKGROUND OF THE PRESENT INVENTION

Field of the Invention

The present invention relates to a system and method for signal demodulation, particularly to a system and method for reducing the computational complexity of demodulating a signal.

Background and Objects of the Present Invention

Digital wireless communication systems are used to convey a variety of information between remotely located users. With digital communications, such information is translated into a digital or binary form, commonly referred to as bits, for communications purposes. A transmitter maps this bit stream into a modulated symbol stream, which is detected at a digital receiver and mapped back into bits whereby information content is conveyed.

In digital wireless communications, however, the radio environment presents many difficulties that impede successful communications. One difficulty is that the signal level can fade as a result of the signal traveling multiple paths due to being reflected, causing some signal images to arrive at the receiver antenna out of phase. This type of fading is commonly referred to as Rayleigh fading or fast fading. When a signal so fades, the signal-to-noise ratio becomes lower, causing degradation in the quality of the communication link.

A second problem occurs when the multiple signal paths have significantly different lengths. In this case, time dispersion occurs, in which multiple fading signal images arrive at the receiver antenna at different times, thereby giving rise to signal echoes or rays. This causes intersymbol interference (ISI), where the echoes of one symbol interfere with that of subsequent symbols.

At the receiver, although coherent demodulation of an incoming signal is desirable for best performance, for such coherent demodulation the characteristics of the multipath channel must be known. However, in many wireless applications, the

multipath channel is time varying due to transmitter motion, receiver motion, and/or scatterer motion. Thus, there is a need to track a time varying multipath channel.

To provide coherent demodulation of multipath signals, a maximum-likelihood-sequence-estimation (MLSE) detector, such as an MLSE equalizer, may be employed. The MLSE equalizer considers various hypotheses for the transmitted symbol sequence, and, with a model of the dispersive multipath channel, determines which hypothesis best fits the received data. An MLSE equalizer may be efficiently realized using a Viterbi algorithm, which is a technique well known to those skilled in the art.

The aforedescribed conventional MLSE equalizer can better be explained by a simple example, such as also set forth in U.S. Patent No. 5,577,068, entitled "Generalized Direct Update Viterbi Equalizer", of which the present inventor is a co-inventor. With reference now to FIGURE 1 of the figures, suppose a transmitter 10, such as a mobile phone, transmits a symbol stream b(n), which takes on +1 or -1 state values corresponding to bit values 0 and 1, respectively. This symbol stream may be modulated using binary phase-shift keying (BPSK). At a receiver 20, such as a base station in a cellular telephone system, the received signal is filtered, amplified, and mixed down using I and Q carriers, then sampled once every symbol period (T), generating a received signal stream r(n). In this example, the intervening channel consists of two fading rays, a main ray and an echo, where the echo arrives T seconds later. Accordingly, the received signal can be modeled as:

$$r(n)= c_0 b(n) + c_1 b(n-1)+ w(n) \qquad (1)$$

where c_0 and c_1 are complex channel tap values and w(n) is additive noise or interference.

In an MLSE equalizer 30 of the present example, also shown in FIGURE 1, at iteration n there would be two different previous "states", 0 and 1, corresponding to the two possible values for b(n-1), i.e., +1(0) and -1(1). Associated with each previous state would be an accumulated metric, accumulated from previous iterations and giving rise to respective accumulated metrics $P_0(n-1)$ and $P_1(n-1)$. There would also

be two current states, corresponding to the two possible values for b(n). Each possible pairing of a previous state with a current state corresponds to a hypothetical sequence $\{b_h(n-1), b_h(n)\}$. For each hypothesis, the predicted, hypothesized received signal value would be:

$$r_h(n) = c_0 b_h(n) + c_1 b_h(n-1) \quad (2)$$

The corresponding "branch" metric would be given by

$$M_h(n) = |r(n) - r_h(n)|^2 \quad (3)$$

The candidate metric for a current state would be the sum of the branch metric and the previously accumulated metric associated with $b_h(n-1)$. As noted, for each current state, there are two possible previous states, where the previous state which gives the smallest candidate metric is selected as the predecessor state. Accordingly, the selected candidate metric becomes the accumulated metric for that current state.

Thus, for current state 0 in the instant example, there would be two hypothetical sequences {+1, +1} and {-1, +1}, referred to as hypotheses h=00 and h=10. This gives rise to two candidate metrics:

$$C_{00}(n) = P_0(n-1) + M_{00}(n) \quad (4a)$$

and

$$C_{10}(n) = P_1(n-1) + M_{10}(n) \quad (4b)$$

In the present example, the smaller of these two candidate metrics gives the accumulated metric for current state 0. The corresponding previous state becomes the predecessor state to state 0 at time n. In other words, if $C_{10}(n) < C_{00}(n)$, then the accumulated metric for current state 0 at time n becomes:

$$P_0(n) = C_{10}(n) \quad (5)$$

otherwise $P_0(n) = C_{00}(n)$. The predecessor state and its predecessor and so forth are referred to as the path history of the current state. A similar procedure is applied to current state 1, in which case the two hypotheses are h=01 and h=11.

The detected symbols are decided by one of two methods. In the first method, all of the data are processed first. Then, the final state with the best metric is determined. The path history of this state (i.e. the predecessor states) gives the detected or demodulated data. In the second method, detection decisions are made before all of the data are processed. At time n, for instance, the symbol transmitted at time $n-\tau$ is decided, where τ is referred to as the decision depth. This is performed by finding the state at time n with the best metric and using its path history to determine the detected symbol at time $n-\tau$.

In general, the time varying channel consists of a number of channel taps that vary with time. After filtering, mixing down to baseband, and sampling, the received data samples r(n) can be modeled as:

$$r(n) = c_0(n)b(n) + c_1(n)b(n-1) + \ldots + w(n) \qquad (6)$$

where b(n) is the transmitted symbol stream, $c_i(n)$ are the time dispersive channel taps, and w(n) is additive noise. It is convenient to use vector notation and to express the received data samples more simply as:

$$r(n) = c^T(n)x(n) + w(n) \qquad (7)$$

where c(n) is a vector of channel taps and x(n) is a vector containing the current and past transmitted symbols. The superscript "T" denotes the transpose.

The demodulator relies on channel tap estimates, $c_{est}(n)$, to predict received values for various hypothetical symbol sequences $x_h(n)$. These predicted values, referred to as target values, $t_h(n)$, are given by:

$$t_h(n) = c_{est}^T(n)x_h(n) \qquad (8)$$

The target values $t_h(n)$ are used to form branch metrics given by, for example,

$$M_h(n) = |r(n) - t_h(n)|^2 \quad (9)$$

or some equivalent metric. These metrics are accumulated and used to determine the demodulated symbol sequence.

The channel tap estimates must be updated to track a time-varying channel. This is done by making a tentative decision as to what symbols were transmitted up to some time n, usually less than the iteration time, and generating a string of symbols, $b_{det}(n)$, $b_{det}(n-1)$..., which can be formed into a vector $x_{det}(n)$. Typically, an error signal e(n) is used to update the channel tap estimates, where the error signal is given by the difference in what was received and what was predicted. The error signal e(n) is given by the equation:

$$e(n) = r(n) - c_{est}^T(n)x_{det}(n) \quad (10)$$

Once the channel taps have been updated, giving $c_{est}(n+1)$, the channel taps can be used to form new predictions, $t_h(n+1)$. A single channel estimate is maintained or multiple channel models (one per state) can be used.

As noted, in the aforementioned MLSE detector, such as the MLSE equalizer 30 shown in FIGURE 1, a sequence estimation algorithm, such as the aforedescribed Viterbi algorithm, is used to determine the most likely transmitted sequence. At each iteration, a number of possible sequences are considered, each resulting in a path metric. For each state, which corresponds to the L most recently transmitted symbols, only one set of sequences is kept, the remainder discarded or "pruned", as is understood in the art. See, for example, U.S. Patent No. 5,191,598 to Bäckström et al. Accordingly, at each iteration, and for each state in the sequence estimation process, candidate metrics may be formed and the best one, e.g., the smallest, becomes the updated path metric. The corresponding previous symbol values then become part of the path history.

In view of the above, it is clear that the complexity of the aforementioned sequence estimation algorithm is nontrivial, particularly where the received signal depends on a greater number of bits. Accordingly, with candidate metrics formed at each iteration and for each state, a considerable amount of computational power is required to perform the requisite operations in the sequence estimation algorithm, such as within the MLSE equalizer 30.

Heretofore, "brute force" approaches have been used where all of the potential candidate metrics are first formed and then compared against one another, e.g., the aforedescribed candidate metrics $C_{00}(n)$ and $C_{10}(n)$ are computed and the resultant values compared. Although some techniques utilize efficient branch metrics and share computations during branch metric formation, these techniques nonetheless compute the full candidate metric, requiring a considerable number of computations, despite the efficiency savings.

Recently, other techniques have been developed for reducing complexity in the path selection (pruning) process for real signals and amplitude modulation. See, for example, M.P.C. Fossorier, "Dynamic Quantization for Maximum Likelihood Sequence Detection of PAM Signaling", *IEEE Trans. Commun.*, Vol. 44, pp. 1444-54, November 1996. In the path selection process, for example, the symbol set is partitioned into a subset of common symbols (L-1 symbols) and a set of differing symbols (1 symbol). This allows the formation of thresholds that are applied to branch metrics or received data values. However, if this approach were extended to complex channels and phase modulation, the computation of the thresholds then becomes increasingly complicated.

It is, accordingly, an object of the present invention to reduce the amount of computation required in a sequence estimation process.

It is a further object of the present invention to provide an alternative to the aforementioned path selection techniques, such alternative being particularly useful for complex channels and phase modulation.

SUMMARY OF THE INVENTION

The present invention is directed to an improved system and method for reducing the computational complexity of path metric updating such as within a maximum likelihood-sequence-estimation (MLSE) detector. MLSE detectors are used, for example, in demodulating a received signal subject to intersymbol interference. Complexity is reduced by eliminating the computation of common portions of a series of candidate path metrics and performing a full computation of the selected candidate metric after the optimum path to the next state has been determined. Alternatively, a primary path metric is determined and key components of secondary path metrics are examined to determine secondary path viability. If the secondary path is viable, the full secondary path metric is formed and compared to the primary path metric, which is replaced if the secondary is better.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described in more detail with reference to preferred embodiments of the present invention, given only by way of example, and illustrated in the accompanying drawings, in which:

FIGURE 1 illustrates a block diagram of a system utilizing the improved demodulation methods of the present invention;

FIGURE 2 gives an example of path metric updating;

FIGURE 3 illustrates a flow diagram according to one embodiment of the present invention;

FIGURE 4 gives a numerical example of path metric updating; and

FIGURE 5 illustrates a flow diagram according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different

forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art.

The system and method of the present invention is directed to improvements in the implementation of a sequence estimation algorithm by reducing the number of computational operations required when forming the candidate metrics. In particular, the proposed solution according to the system and method of the present invention (mode A) is to exploit the presence of common terms appearing within the candidate metrics, and avoiding computations of such duplicative common terms until after the path selection, eliminating a substantial amount of computations pertaining to the potentially numerous non-selected paths.

As noted, in the brute force approach all candidate metrics must be formed and compared even though only one is selected. In conventional MLSE detectors, therefore, all possible data sequences (rather than actually decoding each received symbol by itself) are tested, and that data sequence with the maximum probability as the output is selected. By way of example, consider a computation based upon the Ungerboeck metric where the received signal samples are modeled, as set forth in equation (11), as follows:

$$r(n) = c_0 b(n) + c_1 b(n-1) + c_2 b(n-2) + w(n) \qquad (11)$$

where the c_i are channel tap values, b(n) are transmitted symbol stream values and w(n) is noise. A state at time n corresponds to values for b(n-1) and b(n), and a state at time n-1 corresponds to values for b(n-2) and b(n-1), as illustrated in FIGURE 2. Thus, all candidate metrics for a given state at time n will hypothesize the same values for b(n) and b(n-1), and any terms in the candidate metrics which depend upon these symbols only can be omitted. Using a metric patterned after the aforementioned Ungerboeck technique for discrete-time signals, a branch metric at time n may be expressed as:

$$M(b_h(n-2),b_h(n-1),b_h(n)) = \Re\{b(n)[2z(n) -$$

$$s_0 b_h(n) - 2s_1 b_h(n-1) - 2s_2 b_h(n-2)]\} \quad (12)$$

where $b_h(n)$ corresponds to a hypothetical value for symbol b(n), and

$$z(n) = c^*_0 r(n) + c^*_1 r(n+1) + c^*_2 r(n+2), \quad (13)$$

$$s_o = |c_0|^2 + |c_1|^2 + |c_2|^2, \quad (14)$$

$$s_1 = c^*_o c_1 + c^*_1 c_2, \text{ and} \quad (15)$$

$$s_2 = c^*_o c_2 \quad (16)$$

where superscript "*" denotes complex conjugation. It should be understood from the above that the candidate metrics associated with a particular state will all correspond to the same values for $b_h(n)$ and $b_h(n-1)$. Only the values for $b_h(n-2)$ will differ. Also, let $P(b_h(n-2), b_h(n-1))$ denote the accumulated path metric at time n-1. Accordingly, for path selection purposes, the following partial candidate metrics can be formed, for, for example, the state $\{b_h(n-1) = +1, b_h(n) = +1\}$, as follows:

$$C'(+1, +1, +1;n) = P(+1, +1;n-1) - 2\Re\{s_2\}$$
$$C'(-1, +1, +1;n) = P(-1, +1;n-1) + 2\Re\{s_2\} \quad (17)$$

Whichever is largest is the selected path, which corresponds to some selected value for b(n-2), for instance, -1 in this example.

In view of the above, an updated path metric is then formed using:

$$P(+1, +1;n) = C'(-1, +1, +1;n) +$$
$$\Re\{b_h(n)[2z(n) - s_o b_h(n) - 2s_1 b_h(n-1)]\} \quad (18)$$

It should be understood, however, that if a form of M-ary Phase Shift Keying (MPSK) is used, the s_0 may be omitted and the factors of 2 ignored. A similar process occurs when updating the other state at time n.

While the above example corresponds to binary symbols (+1 and -1), it will be obvious to one of ordinary skill in the art how the invention operates when there are

M possible symbol values and/or the symbol values can be multi-dimensional. For example, with Quadrature Phase Shift Keying (QPSK) modulation, two binary symbols, which form one 4-ary symbol, are sent at the same time, one on the in-phase (I) carrier and one on the quadrature (Q) carrier. At the receiver, the in-phase and quadrature components of the received signal can be extracted. This is typically thought of as complex-valued signal samples, where the real part corresponds to the I component and the imaginary part corresponds to the Q component. Thus, $r(n) = r_I(n)+jr_Q(n)$, where j denotes the square root of -1. The symbol values would then be one of four values: +1, -1, +j, and -j. Thus, for the example above, there would be four candidate metrics, and four partial candidate metrics would be formed. Once three were eliminated, the winning partial candidate metric would be used to form the path metric.

It should be understood that the aforedescribed preferred embodiment of the present invention is directed to improvements in the formation of the aforementioned partial metrics, which are used in path selection. Once the chosen path has been selected from the pack of partial metrics through calculations omitting the common terms therein, only then is the full path metric determined, employing the full amount of computations to the selected metric only. It should, of course, be further understood that the technique set forth in the present invention may be adapted further, such as by partitioning the candidate metrics into subsets with even more common terms so that subsequent terms are added only to the "winners" of the first round of selection.

In an attempt to further describe the preferred embodiment of the present invention, also referred to herein as mode A, it may be stated simply that, in forming candidate metrics, only the parts unique to each previous state are included until after the surviving candidate metric, i.e., the one with the best metric, has been chosen. At that point, the portion of the metric common to the current state is added in once to the surviving metric.

In general, the candidate metrics for current state i at iteration n can be expressed as:

$$C(k,i;n) = C'(k,i;n) + D(i;n) \qquad (19)$$

where k corresponds to a previous state, C'(k,i;n) is the part of the candidate metric that depends at least on k and possibly i as well, and D(i;n) depends only on the current state i at time n. In determining which k is the surviving state, there is no need to consider the term D(i;n) which does not depend on k. Thus partial candidate metrics are computed and compared. The winning metric is then used, with D(i;n) added, to form the new path metric.

Also, it is possible to keep more than one path per state. This is referred to as the list Viterbi algorithm or the generalized Viterbi algorithm. Thus, one might keep B paths per state, where B is typically 1 or 2. A flow diagram of the preferred mode A embodiment is shown in FIGURE 3, where the first step (step 300) is to consider the first iteration. The first state is then considered (step 305), partial metrics formed (step 310) and the best B paths determined (step 315). Full path metrics for the best B paths are then computed (step 320). If further states are to be considered (step 325), control is transferred to step 310. If all states have been considered, a determination is made whether further iterations are needed (step 330). If so, control is shifted back to step 305; otherwise, the process ends.

In an alternative embodiment of the present invention, also referred to herein as mode B, full candidate metrics, starting with the best previous state, are formed, common portions of the computations being used in forming the subsequent metrics. For the aforedescribed Euclidian distance metric, path metrics cannot become smaller (negative distances) and can only get larger. Accordingly, should the extension of the best previous state metric be smaller than the path metrics associated with the other previous states, then there is no need to consider these other previous states further. In an ideal situation, one would extend states starting with the best state and work towards the worst state. It should be understood that in practice, the best state is often known for channel tracking purposes.

An illustration of how this alternative embodiment operates is shown in FIGURE 4 where a "best" or primary state is one having the smallest metric with positive branch metrics, such as the Euclidian distance metric. After formation of the candidate metric for the primary state valued at 75 (previous path metric value 70 plus the indicated branch metric value 5), it is clear that this candidate metric will be less

than the other candidate metrics could possibly be since the other previous path metric is 100. Accordingly, there is no need to compute the other candidate metric. As discussed before, this is readily extended to incorporate complex samples and/or M-ary symbol values.

In the previous example, the primary candidate path is identified by having the smallest previous state metric. After the primary candidate path metric is determined, secondary paths are considered. Instead of computing secondary candidate path metrics, however, only a component, the "key component", of the secondary path candidate metric is examined. In the example, this key component is the previous state metric. The key component is compared to the primary path candidate metric to see if the secondary path could survive. If not, the secondary path is discarded, without needing to compute the full secondary path candidate metric.

In general, the primary path can be identified in a number of ways. It could correspond to the path with the smallest branch metric. Also, the "Key component" for the secondary path could be a branch metric instead of the previous state path metric. A general flow diagram of the operation of Mode B is illustrated in FIGURE 5, which, as with FIGURE 3, considers the first iteration (step 500) and new state (step 505), the primary path is then identified and the primary metric is forward (step 510) and secondary paths are considered (step 515). Key components of the secondary paths are then extracted and compared to the primary metric (step 520). A determination is then made whether a given secondary path is a viable solution (step 525). If so, a secondary metric for that path is formed and compared to the primary metric (step 530). If the secondary metric is better than the aforementioned primary metric (step 535), the primary path and metric are replaced with the corresponding secondary path and metric (step 540).

If the secondary path is not viable (step 525) or the secondary metric suboptimal (step 535) or the primary path has been replaced, a determination is then made whether another secondary path exists (step 545). If so, control is transferred back to step 520 for extraction and comparison; otherwise, a determination is made whether there is another state (step 550). If so, control is transferred to step 510,

otherwise, a determination is made whether there is another iteration (step 555). If so, control reverts back to step 505; otherwise, the process ends.

It should be understood that usage of the techniques of the present invention depend upon the signal-to-noise ratio (SNR). Where the SNR is high, i.e., signal fidelity is good with low distortion, typically only one candidate metric is formed. Consequently, there is little need for a path determination. With decreasing SNR, however, multiple paths are possible and multiple candidate metrics are formed. Accordingly, the computation reduction techniques set forth in the present invention may be turned on and off in accordance with the amount of signal interference present, switching between a mode A (low SNR) and a mode B (high SNR) in accordance with signal conditions.

Criteria for switching from mode A (a poor signal environment) to mode B (good signal environment) may include:

(a) favorable frame erasure rate (FER), carrier/interference level ratio (C/I), average bit error rate (BER) or other figure of merit, such as the BER of the sync word;

(b) consistent dominance of one path metric over others; and

(c) occasional switch to the alternate mode to determine if the system, or, in particular, the receiver, can operate better in that mode. If not, the system switches back.

Alternatively, criteria for switching from mode B to mode A may include:

(d) all or most candidate metrics are being consistently computed; and

(e) the aforedescribed FER, C/I, average BER, etc., may also be used.

It should be understood that the techniques set forth herein can be applied in various other contexts other than that of MLSE equalization and may be applied to any modulation, including amplitude and phase modulation. It should further be understood that the present invention is applicable to a variety of branch metrics, including Forney, Ungerboeck, direct update, and the partial Ungerboeck metric

discussed in U.S. Patent No. 5,449,272 to Bottomley. The present invention is further suitable for use with adaptive channel estimation, although channel tracking error signals may be required.

It should also be understood that the techniques of the present invention may be extended to include fractionally-spaced equalization, diversity, multi-user detection, and per survivor processing (multiple channel models). Furthermore, other MLSE applications are contemplated within the scope of the present invention, including convolutional decoding and coded modulation decoding (both trellis and block). It should additionally be understood that the present invention may also be used in conjunction with other sequence estimation algorithms (list Viterbi, Fano algorithm) as well as algorithms with more pruning, such as the M and T algorithms, or tree searching with pruning.

While the present invention has been described with respect to digital symbol detection using a sequence detection algorithm, the present invention is also applicable to other applications involving dynamic programming. In general, dynamic programming involves finding the best combination of items. A typical example is the traveling salesman problem, in which the goal is to find the shortest route from point A to goal is to find the shortest route from point A to point B across a number of different pathways therebetween. The goal is to find the set of roads that minimizes the distance traveled.

The previous description is of preferred embodiments for implementing the invention, and the scope of the invention should not necessarily be limited by this description. The scope of the present invention is instead defined by the following claims.

WHAT IS CLAIMED IS:

1. A radio receiver for demodulating digital information containing a plurality of data samples therein, said radio receiver comprising:

symbol detection means for receiving a given one of said data samples and for detecting a symbol sequence therein; and

calculating means for calculating, based upon a previous-state metric for said symbol sequence, a particular current-state metric for said symbol sequence, said calculating means selecting said particular current-state metric from a multiplicity of candidate metrics, a first multiplicity of said candidate metrics including at least one common operator therein, said calculating means calculating a current-state metric for each of said first multiplicity of candidate metrics without said at least one common operator, said calculating means selecting said particular current-state metric and calculating said particular current-state metric for said symbol sequence with said common operator.

2. A base station in a wireless telephone system, said base station in communication with a plurality of mobile phones within said wireless telephone system via a corresponding plurality of radio signals, said radio signals including a sequence of symbols therein, circuitry within said base station for demodulating the symbol sequence of a particular one of said radio signals, said circuitry comprising:

a receiver for receiving said plurality of radio signals;

a sequence estimation detector for calculating, based upon a previous-state metric of a given symbol sequence within said particular radio signal, a particular current-state metric for said given symbol sequence, said sequence estimation detector selecting said particular current-state metric from a multiplicity of candidate metrics, a first multiplicity of said candidate metrics including at least one common operator therein, said sequence estimation detector calculating a current-state metric for each of said first multiplicity of candidate metrics without said at least one common operator, said sequence estimation detector selecting said particular current-state metric from said multiplicity of candidate metrics, and calculating said particular current-state metric for said given symbol sequence with said common operator.

3. A sequence detector for detecting a symbol sequence of digital information, said sequence detector comprising:

metric generation means for generating a multiplicity of partial candidate metrics corresponding to a state within said sequence detector;

selection means for selecting a given one of said multiplicity of partial candidate metrics to produce a selected partial candidate metric;

second generation means for generating a common metric associated with said multiplicity of partial candidate metrics and corresponding to said state; and

path metric formation means for forming a path metric using said selected given partial candidate metric and said common metric.

4. The sequence detector according to claim 3, wherein said second generation means generates said common metric using a plurality of received data samples of said digital information.

5. The sequence detector according to claim 3, wherein said second generation means generates said common metric using a plurality of hypothetical symbol values based upon said digital information.

6. The sequence detector according to claim 3, wherein said selection means selects a multiplicity of said partial candidate metrics, producing a corresponding multiplicity of selected partial candidate metrics.

7. A sequence detector for detecting a digital symbol sequence within a digital information stream, said sequence detector comprising:

selection means for selecting a primary previous state for said sequence detector, said primary previous state having a path metric corresponding thereto;

formation means for forming candidate metrics using said path metrics of said primary previous state and a plurality of other previous states;

comparison means for comparing said candidate metric corresponding to said primary previous state to the path metric corresponding to a secondary previous state, said comparison means producing an indicator based upon said comparison; and

inhibitor means for inhibiting said candidate metric formation by said formation means pursuant to the value of said indicator.

8. A sequence detector for detecting a digital symbol sequence within a digital information stream, said sequence detector comprising;

ordering means for ordering a plurality of previous states for said sequence detector pursuant to the values of a corresponding plurality of metrics associated therewith;

formation means for forming a candidate metric using a given one of said previous states;

comparison means for comparing said candidate metric to the metric of another previous state of said plurality of previous states, said comparison means producing an indicator based upon said comparison; and

selection means for selectively forming, pursuant to the value of said indicator, at least one candidate metric using said another previous state.

9. An adaptive sequence detector for detecting a digital symbol sequence within a digital information stream, said adaptive sequence detector comprising:

a first current state metric calculator comprising:

formation means for forming a plurality of partial candidate metrics and, using said partial candidate metrics, forming a plurality of current state metrics; selection means for selecting at least one of said current state metrics; and

addition means for adding a common metric to said at least one current state metric, said common metric having a component in common with each of said plurality of current state metrics;

a second current state metric calculator comprising:

formation means for forming a plurality of candidate state metrics and, using said candidate state metrics, forming a second plurality of current state metrics; and

comparison means for comparing said plurality of candidate state metrics to a plurality of previous state metrics to selectively inhibit said candidate state metric formation; and

calculation selection means for selecting between said first and second current state metric calculators.

10. The adaptive sequence detector according to claim 9, wherein said calculation selection means utilizes a signal-to-noise indicator for said digital information stream.

11. The adaptive sequence detector according to claim 9, wherein said calculation selection means utilizes a signal quality indicator for said digital information stream.

12. The adaptive sequence detector according to claim 9, wherein said calculation selection means utilizes a plurality of performance indicators for said previous state metrics.

13. An adaptive sequence detector according to claim 9, wherein said calculation selection means periodically switches between said first and second current state metric calculators.

14. A device for determining an optimal combination of items comprising:

metric formation means for forming a plurality of candidate metrics corresponding to a plurality of sets of said items;

comparison means for comparing the candidate metric corresponding to one of said plurality of sets to another metric associated with a second set of said items, said comparison means producing an indicator based upon said comparison; and

inhibitor means for inhibiting said candidate metric formation by said metric formation means pursuant to the value of said indicator.

15. An adaptive device for determining a combination of items comprising:

a first current state metric calculator comprising:

formation means for forming a plurality of partial candidate metrics and, using said partial candidate metrics, forming a plurality of current state metrics; selection means for selecting at least one of said current state metrics, and

addition means for adding a common metric to said at least one current state metric, said common metric having a component in common with each of said plurality of current state metrics;

a second current state metric calculator comprising:

formation means for forming a plurality of candidate state metrics and, using said candidate state metrics, forming a second plurality of current state metrics, and

comparison means for comparing said plurality of candidate state metrics to a plurality of previous state metrics to selectively inhibit said candidate state metric formation; and

calculation selection means for selecting between said first and second current state metric calculators.

16. A device for determining an optimal set of items, said device comprising:

association means for associating a metric to a set of said items;

formation means for forming a multiplicity of partial candidate metrics corresponding to a multiplicity of candidate sets of said items, said candidate sets being a subset of said set;

selection means for selecting a given candidate set from said multiplicity of candidate sets, said given candidate set being selected pursuant to the values of said multiplicity at partial candidate metrics;

means for forming a common metric associated with said set of items; and

combining means for forming a combined metric using said partial candidate metric associated with said given candidate set and said common metric.

17. A method for demodulating a symbol sequence, a previous-state metric being associated with said symbol sequence, a particular current-state metric for said symbol sequence being based upon said previous-state metric, said method comprising the following steps:

calculating, based upon said previous-state metric, a multiplicity of candidate metrics for said symbol sequence, a first multiplicity of said candidate metrics including at least one common operator therein;

calculating a current-state metric for each of said first multiplicity of candidate metrics without said common operator;

selecting said particular current-state metric from said first multiplicity of candidate metrics; and

calculating said particular current-state metric for said symbol sequence with said common operator.

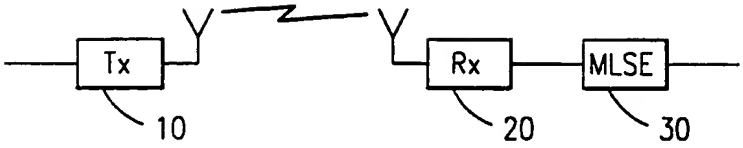
Tx
Rx
MLSE
10
20
30

FIG. 1

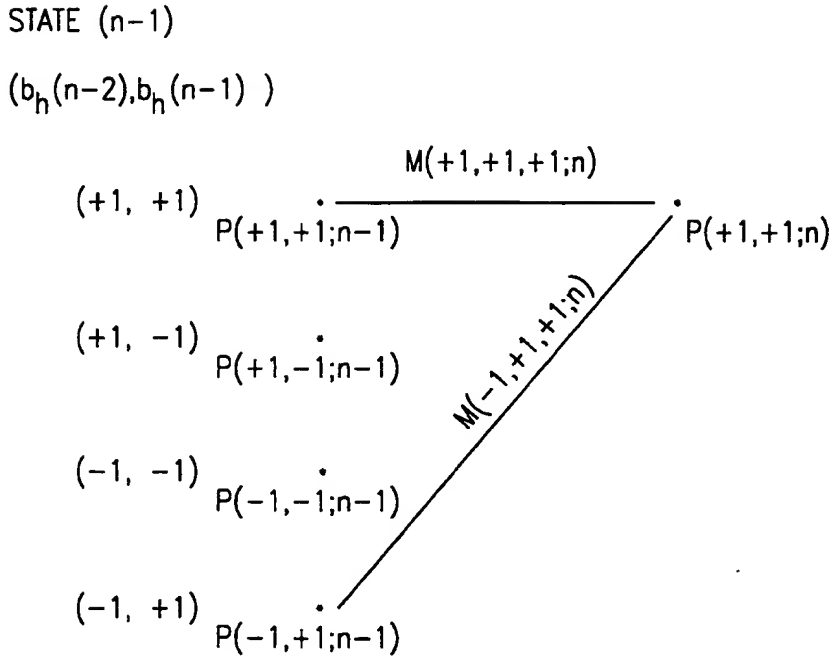
STATE (n-1)
$(b_h(n-2), b_h(n-1))$
M(+1,+1,+1;n)
(+1, +1)
P(+1,+1;n-1)
P(+1,+1;n)
(+1, -1)
P(+1,-1;n-1)
M(-1,+1,+1;n)
(-1, -1)
P(-1,-1;n-1)
(-1, +1)
P(-1,+1;n-1)

FIG. 2

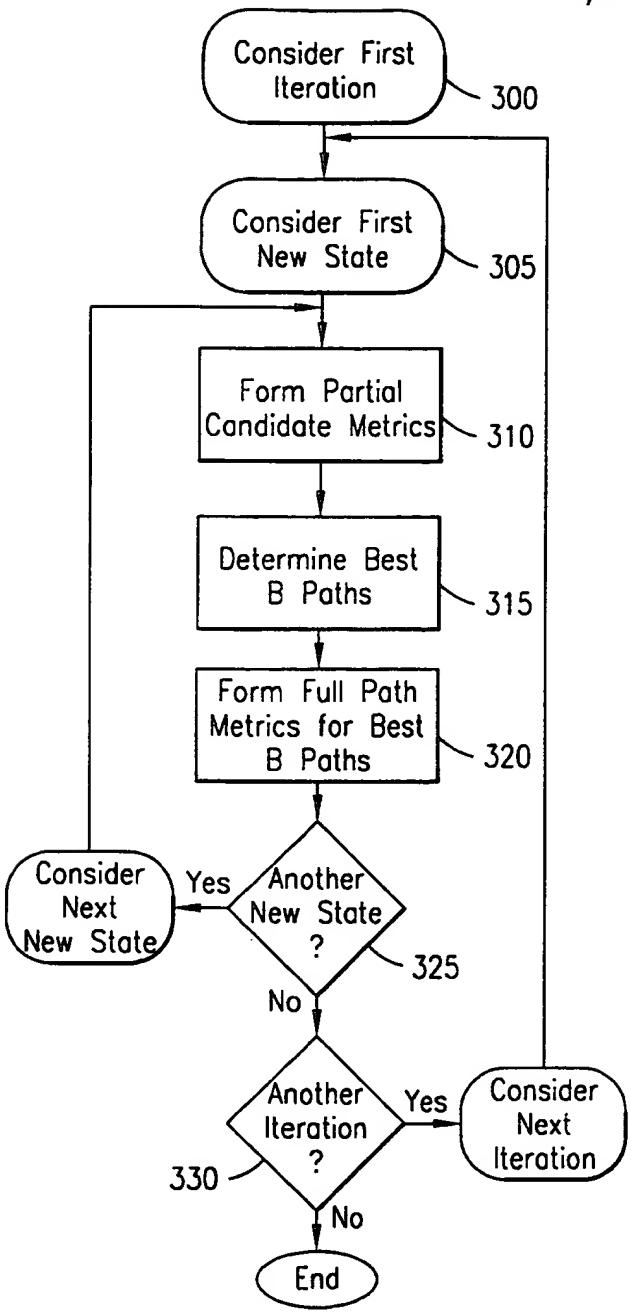
Consider First Iteration
300
Consider First New State
305
Form Partial Candidate Metrics
310
Determine Best B Paths
315
Form Full Path Metrics for Best B Paths
320
Another New State ?
325
Yes
Consider Next New State
No
Another Iteration ?
330
Yes
Consider Next Iteration
No
End

FIG. 3

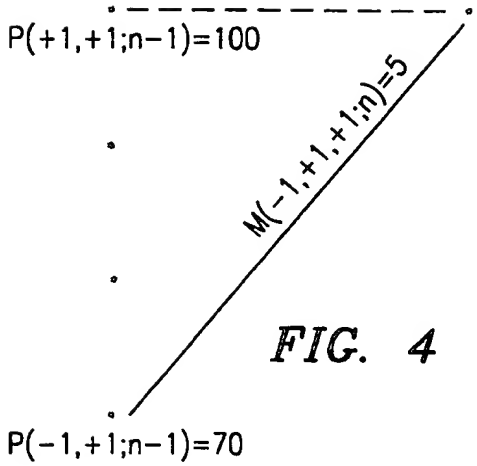
P(+1,+1;n-1)=100
M(-1,+1,+1;n)=5
P(-1,+1;n-1)=70

FIG. 4

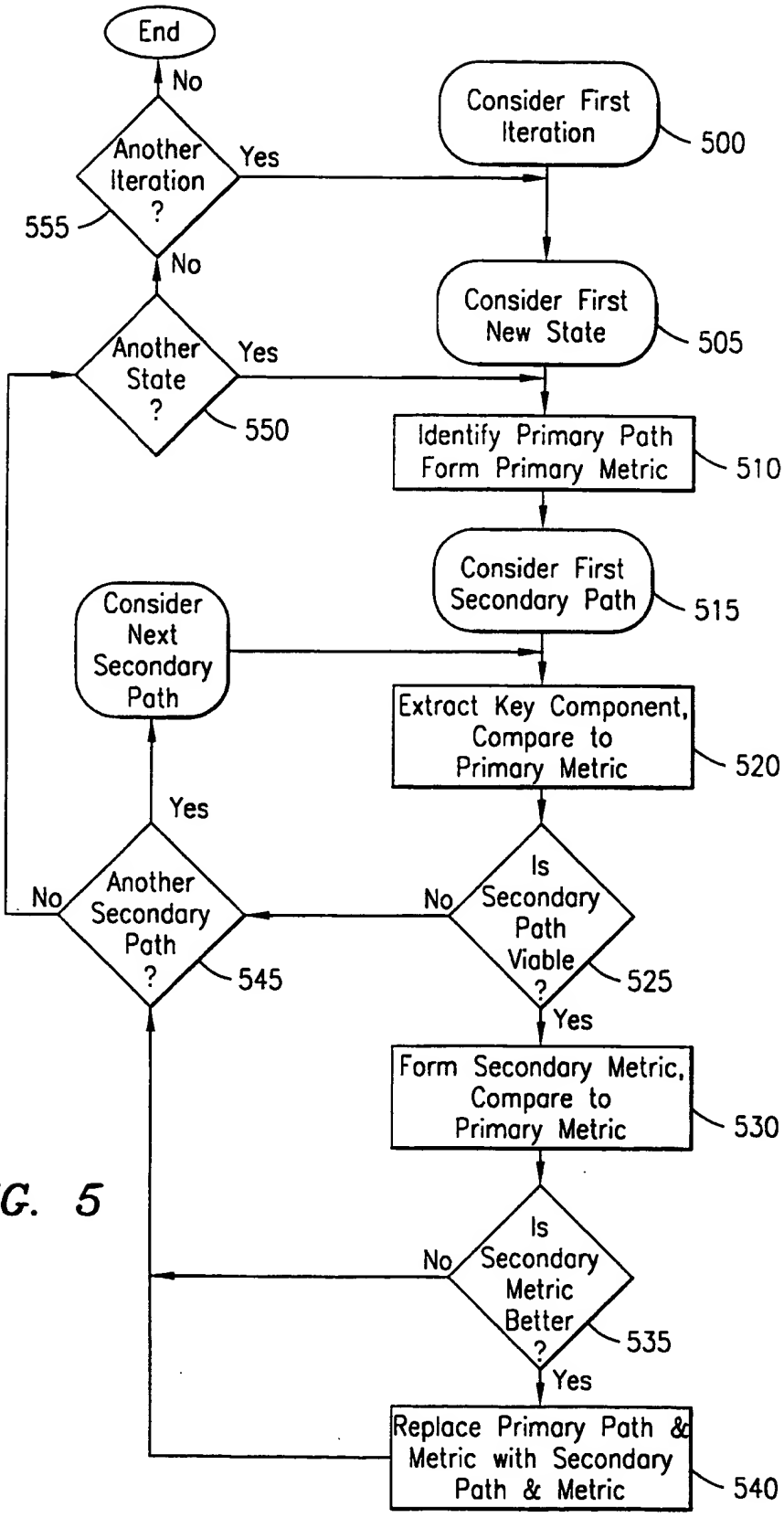
End
No
Another Iteration ?
Yes
555
Consider First Iteration
500
No
Another State ?
Yes
550
Consider First New State
505
Identify Primary Path Form Primary Metric
510
Consider First Secondary Path
515
Consider Next Secondary Path
Extract Key Component, Compare to Primary Metric
520
Yes
No
Another Secondary Path ?
545
No
Is Secondary Path Viable ?
525
Yes
Form Secondary Metric, Compare to Primary Metric
530
No
Is Secondary Metric Better ?
535
Yes
Replace Primary Path & Metric with Secondary Path & Metric
540

FIG. 5

INTERNATIONAL SEARCH REPORT

Interi nal Application No
PCT/US 98/27186

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04L25/03

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04L H03M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 632 623 A (OKI ELECTRIC IND CO LTD) 4 January 1995 see abstract see page 4, line 56 - page 5, line 38 see claim 1	1-17
A	US 5 375 129 A (COOPER ANDREW) 20 December 1994 see abstract	1-17
A	US 5 581 568 A (TOGAMI MIKIO) 3 December 1996 see abstract see column 3, line 19 - line 34	1-3,9, 15-17

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
7 April 1999	14/04/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Koukourlis, S

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INTERNATIONAL SEARCH REPORT

Inter. nal Application No
PCT/US 98/27186

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 499 272 A (BOTTOMLEY GREGORY E) 12 March 1996 cited in the application see abstract see column 2, line 33 - line 43 see column 2, line 46 - column 4, line 20 -----	1-3,9, 15-17

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INTERNATIONAL SEARCH REPORT

...ormation on patent family members

Intern... ...al Application No
PCT/US 98/27186

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